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FLEXIBLE MANUFACTURING SYSTEMS (FMS): A REVIEW

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ABSTRACT

Today's manufacturing environment demands for manufacturing performance to accomplish the task in the stipulated time interval. Hence, flexibility of the manufacturing systems becomes an important issue which has led to the development of Flexible manufacturing systems (FMS). This unique production system encapsulates various components such as a computer programmed machine tools, automated material handling systems, robots, and Inspection and self diagnostic facilities into a single production system. FMSs are recognized by the replacement of computer control set up of the hard mechanization generally found in exchange lines. The high venture required for a FMS and the capability of FMS as a key aggressive device makes it alluring to take part in exploring around there. This paper presents a review related to the various aspects of FMS. Articles underscoring numerous methodological points of view are basically audited. It is believed that this article results in bridging the gaps between the various crucial aspects required for its implementation.

KEYWORDS: Flexible Manufacturing Systems (FMS), Scheduling; Mathematical Model, Tools & Route Path

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Review Article

1. INTRODUCTION

The new challenges in the contending business can be encountered by modern manufacturing systems. The introduction of Flexible manufacturing System (FMS) has paved the way for the manufacturing industries to improve their performance together with attaining the flexibility. It facilitates the combination of high levels of flexibility, high productivity and low level of work- in-process inventory [1]. Flexibility is regarded as an attribute that provides a manufacturing system to withstand a certain level of variations in partial styles without any interruption in production line. When flexibility exists throughout the life cycle of a product, only then system is regarded as a flexible system. The flexibility of the production system can be determined by different tests such as part variety, schedule change, error recovery and new part test. Browne et al. [2] studied various types of flexibilities in his research work. It included routing, machine, operation, production, expansion, process, product and volume. After few years, Sethi and Sethi [3] added material handling, program, and market flexibility criteria to the earlier flexibilities.

The concept of FMS is that it merges the ideology of flow shop and batch shop manufacturing system. Further, it is architecture in such way that the flexibility of job shops is achieved along with accomplishing the effectiveness of dedicated production systems. Also, care must be taken to meet the demands with decreasing time. It is learnt that through FMS, different products with various batch size scans are manufactured simultaneously.

It is learnt from the literature that there are three major components of FMS, i.e., workstations, automated material handling with storage system and a central computer. Workstations are processing stations of FMS, which are involved in performing operations on the part types. For transferring of parts from one station to another, an automated

material handling system is used, while central computer is used for controlling and coordinating the performance of workstation and material handling system.

2. DIFFERENT TYPES OF FLEXIBILITIES

The various forms of flexibilities involved in FMS can be summarized as follows:

- **Process flexibility**: A particular part produced with different types of process is called Process flexibility.
- **Material handling** flexibility: The path process employed between machines is the concern.
- **Machine flexibility**: A single set up is used to perform different operations.
- **Operation flexibility**: The processing plans vary with respect to production of a part.
- **Product flexibility**: With the existing product mix, different products are developed.
- **Routing flexibility**: The achievable routes of the product to be developed are of importance.
- **Volume flexibility**: Variation in the volume of production.
- **Expansion flexibility**: Flexibility related to the capacity of production.
- **Production flexibility**: Without the variation in capital of the equipment, flexibility is achieved for all types of parts.
- **Control Program flexibility**: Flexibility related to the use of intelligent materials.

Need for Flexible Manufacturing Systems (FMS)

The flexible manufacturing systems have considered as a boon for many of the production and development industries. The reason behind this can be encapsulated as follows:

- In rapid market changes, the low volume and low production cost can be handled with ease using FMS.
- Increased competition at international platform.
- To achieve improved market response.
- To have flexibility in the production.
- Substantial improvement in the product quality.
- To fulfil customer requirements with ease.
- Reduced production time.
- Reduced cost incurred.
- Reduced labor cost.

Drawbacks of FMS

- Expensive.
- Complexity in setup.
- Requirement of skilled labor.

Components of FMS

Shore et al. [4] categorized few important components of FMS as illustrated below:

- Pallet and Fixtures
- Machining centers
- Inspection equipment
- Chip removal system.
- Storage systems.
- Material handling systems.

3. MODELING IN FMS: SCHEDULING AND CONTROLLING ISSUES

The FMS operations are dealt by many researchers. Mainly, they have been classified into mathematical programming approach, multi-criteria decision making approach, Heuristics oriented approach, Control theoretic approach, Simulation based approach and Artificial intelligence (AI) based approach. The prominent outcomes from the literatures dealing with the each technique can be summarized as follows:

Mathematical Programming Approach

Considering the case of mathematical programming approach, Buzacott and Yao [5] proposed that the analytical methods yield better results than the simulation models. Stecke [6] subdivided the FMS operation preproduction setup and production operation, respectively. They also emphasized on the preproduction setup of the FMS. The complete FMS setup includes Part type selection problem, Machine grouping problem, Production ratio problem, Resource allocation problem and Loading problem. Berrada and Stecke[7] have proposed an efficient branch and bound procedure for solving the loading problem with the objective of workload balancing. Stecke and Solberg [8] recommend unbalancing the workload for each machine when the pooled group sizes are unequal in order to obtain maximum production rate. Lashkari*et al.* [9] considered re-fixturing and limited tool availability and developed a formulation of the loading problem. The specialty of this technique is it will permit only one allocation of a machine to an operation, which improves the flexibility of the operation control. With a slight modification, a better, simpler and direct formulation was proposed by Wilson [10], Shanker and Rajamarthandan [11]. Han *et al.* [12] in their model, optimized the number of tools used in the process which facilitates assigning tools and jobs to machines, thereby minimization of tool borrowing can be achieved. With the elapse of time, this mathematical model approach became a topic of research which was dealt and improved by many researchers [13-22].

Multi Criteria Decision Making Approach

Since, it is believed that FMS deals with the process involving multiple criteria, few authors focused on this issue while developing models. Through goal programming, Lee and Jung [23] solved the part selection and allocation problem. It is found that their model can act as a better decision maker with enhanced solution accuracy. For the purpose of providing more number of feasible solutions, Kumar *et al.* [24] proposed a multi-criteria approach. Analogously, Ro and Kim [25] and O'Grady and Menon [26] discussed the multiple criteria in detail. In recent, Karsak[27] used fuzzy hierarchy process to solve FMS selection problem. Rao [28] incorporated diagraph and matrix method for FMS selection. Rao and Parnichkun [29]; Chatterjee and Chakraborty[30] using FMS selection index matrix, ranked different alternatives of FMS. Further, many methods were modeled to the machine tool utilization [31-35]. Combining Tabu search and simulated annealing method Low et al. [36] resolved FMS scheduling issues.

Heuristics Oriented Approach

In the above mentioned approach, it was noticed that the use of mathematical computations were cumbersome. This led to the development of Heuristics oriented approach. It generally takes the form of dispatching rules [37-40]. Nof*et al.* [41] explored different aspects of scheduling and planning. They summarized from their study that the outcome of a problem is directly related to the choices made from other problem. The usage of the dispatching rules was evaluated by Stecke and Solberg [42]. They found that extremely unbalanced loading of the machines caused by the part movement minimization objective gave consistently better performance than balanced loading. The very prominent decision rules to take entire FMS into control were dealt by Iwata et al. [43]. The more research on the dispatching rules can also be found in literature [44-52].

Control Theoretic Approach

Noticing, the drawbacks of the Heuristics oriented approach, a new control theoretic approach evolved [53]. It also included closed loop formulation (Kimemia and Gershwin [54]; Akella*et al.* [55]), discrete time control method (Han and McGinnis [56]). The motto of this control theoretic scheduling policy is to achieve a steady safety buffer of the parts produced in the FMS, as long as it is feasible to do so. A characteristic of the framework is that it is constrained to find a solution within the production capacity of the FMS.

Simulation Approach

Few pioneers considered a discrete event simulation as a prominent scheduling tool which uses data from actual FMS for simulation Davis and Jones [57]. The scheduling system developed by Jain *et al.*[58] communicates on-line with the factory control system, generating schedules in real-time. Earlier works on such controlling systems are reported by Wu and Wysk [59], Ishi and Talavage [60]. More recently, Matsui et al. [61] maximized throughput rate of the system and examined the efficiency of the FMS. Further, Potts and Whitehead [62] extended this study for three phase stage. Using Taguchi design, Chan [63,64] evaluated the effect of various parameters such as pallet number, routing levels and dispatching rule on the performance of FMS. A similar study was reported by Ali and Wadhwa [65] to investigate the performance of a flexible system of integrated manufacturing (FSIM) with the aid of analysis of variance (ANOVA) and Taguchi's technique. Caprihan and Wadhwa[66] investigated the effect of information delay on the selection of best routing flexibility levels of FMS. Chan et al [67] studied the direct effect of real time control on the FMS performance. The effect of various routing flexibilities under different aspects of FMS was dealt with Joseph and Sridharan [68],

Singholi et al. [69-71], Dosdogru et al. [72,] Son and Park [73], Jain and Raj [74], Kumar and Sridharan [75]. The part input sequence was optimized by Cheng and Chan [76] for production planning using simulation models. In multistage production system, Gyulai et al. [77] calculated production plan for assembly lines through simulation method. Similar contributions have also been reported towards developing various simulation models for the accurate evaluation of different aspects of FMS performance [78-83].

Artificial Intelligence Approach

The problems where human expertise can find reasonable solutions pretty fast, artificial intelligence approach are used. Steffen [84] has presented a survey of AI based scheduling systems. Kusiak and Chen [85] have also reviewed a number of AI-based scheduling approaches. Further research on AI in FMS was carried out by emphasizing much on scheduling production in general [86-90]. Considering if-then rule [91, 92], object-oriented programming [93-95], rule based system [96], nonlinear planning algorithm [97]the process was determined.

4. BIFURCATION OF FMS

The previous section deals with the literature survey highlighting the methodological approach used. In this section, the various FMS's are scrutinized and bifurcated based on their complexity. They are

- Dedicated FMS
- Random FMS
- Flexible Assembly Systems

In case of dedicated FMS's, the focus is laid on a few of the pre-selected parts of the system [9, 10, 14, 23, 24, 25, 26, 50, 60, 98, and 99]. However, the random FMS's deals with a broad variety of machine parts [11, 15, 22, 48, 49, 58, 59, 100-103]. Finally, Flexible assembly systems are concerned with more specialized assembly of machine parts.

5. HURDLES ENCOUNTERED IN FMS

This section addresses the major issues which are generally faced in the FMS.

Machine Loading

Machine loading can be defined as a set of tools that are required to produce parts using different resources such as material handling systems, pallets, jigs and fixtures and considers how the parts are assigned so that optimum productivity can be reached [104]. It is related to assigning different jobs to the different machines by taking into consideration the technical constraints and accomplishing the performance. It includes various flexibilities of the process such as operation assignment, part selection, machine capacity, cost, over utilization, etc. The different objectives of machine loading includes the minimization of flow time, inventory and manufacturing costs, re-fixturing stations, tool transport system, makespan, unbalance, tardiness etc. Analogously, maximization of alternate routings, total profit and machine load differences are also considered. Table 1 encapsulates the most prominent researches on the machine loading problem encountered in FMS.

Table 1: Literatures on Machine Loading Issues in FMS

Literature	Objective	Findings
K. E. Stecke& F. Brian Talbot	Balancing and unbalancing of workload	Proposed a method to load tool magazine in FMS
K. Shankar & Y. J. Tzen	Number of late jobs	Proposed a computational method with improved results
J. A. Ventura, F. F. Chen, & M. S. Leonard	Minimization of make span	The performance of the FMS is improved
B. Ram, S. Sarin, & C. S. Chen	Maximisation of throughput	The loading time was minimized
S. K. Mukhopadhyay, S. Midha,& V. Murlikrishna	Maximisation of throughput	Improved efficiency of FMS
K. Kato, F. Oba, & F. Hashimoto	Minimization of cutting tools	Algorithm was proved reliable
E. K. Steeke& F. Brian Talbot	Balancing of workload	Computational efficiency improved
M. K. Tiwari et al.	Minimize system unbalance	System balance was successfully achieved
G. K. Nayak& D. Acharya	Maximizing routing flexibility of batches	Overall system performance has improved by routing flexibility of the batches
N. Nagarjunaa, O. Maheshb, & K. Rajagopal	Minimizing system unbalance	Flexibility of job shops
M. Goswami& M. K. Tiwari	Maximizing throughput	Operational decisions are successfully achieved
M. K. Tiwari, J. Saha, & S. K. Mukhopadhyay	Maximizing throughput	The approach proposed was efficient in terms of solution quality

Layout Design

In FMS, resolving the issues concerned with layout design is crucial and requires attention at the beginning stage of the process. The role of layout designer is of much importance due to the fact that FMS uses expensive hardware and requires various alternate layouts. A proper design of layout facilitates minimization of transfer time there by increasing the productivity of the unit. In this regard, Kusiak [105] proposed a multilevel decision model. It takes into consideration the issues related to vehicle and machine scheduling. Nayak and Acharya[106] evaluated the problems of continuous facility layout problems. With the aid of composite mutation strategies, Nagarjuna et al. [107] addressed the issues of artificial bee colony. Hajinejad minimized total flow time by developing Particle swarm optimization algorithm. Park et al. [108] aimed at reducing the material handling cost by developing genetic algorithm which optimized the facilities layout with ease.

Since, the better decision with respect to FMS layout can be taken only in combination with the decisions related to the capacity of the workstation, storage units and material handling system, few researches evaluated the dependency of layout design on these factors. Steeke and Talbot [109], Shankar and Tzen.[110] estimated the influence of material handling system on layout design. The effect of storage capacity on layout design was studied in detail by Tiwari et al. [111]. The optimum location of the storage cell in a FMS is studied by Tiwari et al. [112] and Ventura et al. [113]. The problem related to queuing was dealt by Villa et al. [114] and Wu and Wysk[115].

Tool Management

A major role in FMS is played by tool management. According to Young and Rossi [116], it can be defined as getting the right tool, to the right place and at the right time. The necessity originated from the utilization of high variety and number of cutting tools that are frequently used in automated manufacturing systems. A suitable decision on tool management yields high productivity, thereby increases the profit of the firm. Also, it facilitates efficient part mix and manufacturing quantities. The various features such as tool switching, tool allocation and tool sharing are considered as the integral parts of tool management.

Planning

The decision or enrouting phase of the automated manufacturing process is known as Planning. The significant subdivisions under this issue include sequencing, scheduling and loading. This phase is concerned with running the FMS by optimally scheduling the flow parts. From the part numbers which are to be processed on the system, subsets are made pertaining to the production orders, requirements from another department in the factory or from a sister plant or customer orders, or maybe forecasted demand. The optimum scheduling can be accomplished by incorporating techniques like Hierarchy method, Heuristic approach [36], Sequence improving procedure and Route exchanging procedure [56], dispatching and knowledge rule [15], break and build model [73], simulation based model [77].

CONCLUSIONS

In this article, an exhaustive literature survey dealing with the preliminaries of flexible manufacturing system has been carried out. A special has been paid on modelling approaches in FMS, as studied by different pioneers. Also, the literatures dealing with the bifurcation of FMS and various issues concerned in FMS give the reader a brief insight on the actuality of the FMS in industries. It is noticed from the survey that among many modelling techniques, mathematical models are found to be prominent, whereas for evaluating the various system performance, simulation technique proves to be worthy. In addition, with the aid of AI technique, an effective control of FMS can be achieved. This article has made a solemn attempt to highlight the issues and problems related to FMSs, starting from their planning to implementation. However, the exhaustive literature of FMS indicates that still this field has ample room for further research.

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